AUTOMATED ANALYSIS OF DISTRIBUTION GRID PROTECTIVE SCHEMES

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ABSTRACT

Within Stedin (a Dutch grid operator) a project has started where the protective system of the distribution grids are evaluated. The Stedin service area consists of 170 distribution grids, hence an automated approach is chosen. In this paper the automated analysis as well as the results from the project are discussed.

INTRODUCTION

The society's dependency on electrical energy is greater than ever and will keep increasing in the near future. Major power system disturbances and outages have a significant economic and social impact and the issue of security of supply becomes even more important. However, electric power systems are subjected to all kinds of events leading to disturbances of its proper behaviour. Large disturbances, usually related to faults, are accompanied by large current and voltage excursions which can lead to serious equipment damage. These abnormal system conditions have to be recognized and appropriate actions have to be taken by the protective system. The performance of the protective system has a significant impact on power system reliability. In order to minimize the impact of faults, a proper protection relay coordination is essential.

Problem definition

Stedin is a merge of a number of local communal energy companies and its predecessor is established twenty years ago. At that time each individual company had its own standards in grid topology and protection philosophy, each one having their own pro's and con's. Due to the evolution in time and the company's changing environment, knowledge on the original protection philosophy started to disappear. As a result, some network faults were not switched off as expected or intended by the protection philosophy, resulting in a larger outage than needed. Considering society's increasing dependency on electric energy, this behaviour is unacceptable. Therefore a project has started in which all transmission and distribution grids in the Stedin service area will be checked on a proper protective system. As a second part of the project all protection settings, relay types and related software and firmware running at the relays, are logged in a central system.

Project Approach

The network in the Stedin service area can be divided into approximately 170 distribution grids (10, 13 and 23 kV) and about 20 sub-transmission grids (23, 25 and 50 kV). This project has been split into two parts:

1. Analysis of the protective system of the distribution and sub-transmission grids
2. Collection of the data of the protection relays

This paper mainly focuses on the first part of the project. Related to this project part the following research questions are defined:

- What is the acceptable performance of the protective system?
- What protection problems do occur in current sub-transmission and distribution grids?

The first step in the project is the definition of a procedure to analyse the performance of the protective system. In this way all networks are analysed in a uniform way. Since a large number of distribution grids had to be examined, the analysis should be automated. Together with our main supplier of simulation software the defined procedure is developed and implemented in the software. All distribution grids are modelled in a predefined way, which is suitable for automated analysis in the simulation software. Within these models all protection relays including the actual protection settings are implemented. The first result of the analysis is a subdivision of networks that do have an acceptable performance of the protective system and networks that need further investigations.

At the end of the project all networks are analysed and new protection settings are adapted in the networks where a change was necessary. At some substations this can result in a replacement of old electro-mechanical relays by new standardized Intelligent Electronic Devices (IED). The results are distribution grids with properly coordinated and selective protective systems, which meet the requirements defined in the beginning of this project. Since all networks including protection relays are considered, all actual settings are filed into a central database.

PROTECTION PHILOSOPHY

An important part of the project is the definition of a standard protection philosophy including a standard procedure to determine the protection relay settings. Ultimately at the end of the project this results in distribution grids which are protected using the standard protection philosophy and standardized relay coordination. However, in some specific grid situations it may be necessary to deviate from the standard protection philosophy in order to guarantee a properly coordinated protective scheme. In this section a brief discussion of the standardized protection philosophy is given.

Distribution grid protection

The main requirements of the protection philosophy are:

- Simple
- Selective with underlying protection
- Fault clearing time as short as possible to limit component damage and prevent of voltage dips

In figure 1 a generic overview of a distribution grid structure is depicted. In this figure circuit breakers are drawn including various protection functions and are denoted with the letters A-E. This figure holds for the following 50/10 kV, 50/13 kV, 25/10 kV transformer ratio’s as well as 10 and 13 kV distribution grids.

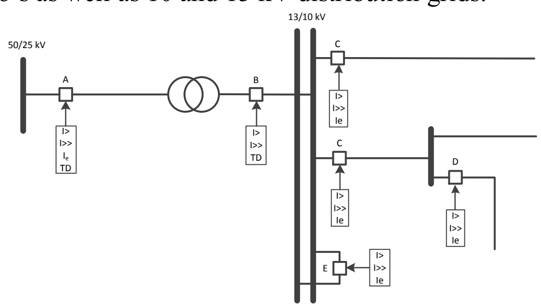

Figure 1: *Distribution grid protection philosophy*

The transformer is protected via the protection relays acting on circuit breakers A and B. The transformer’smain protection is the transformer differential protection (TD) in combination with Instantaneous Over Current (IOC) protection which acts as a backup protection.

The IOC protection at circuit breaker B is equipped with two pickup levels. The $I_{>>}$, $t_{>>}$ pickup level protects the busbar while the $I_{>}$,$t_{>}$ pickup level has the function of a backup protection of the outgoing feeders.

The IOC protection at circuit breakers C and D protect the actual distribution grid. Depending on the neutral point grounding the $I_{>>}$-$t_{>>}$, $I_{>}$-$t_{>}$ settings are applied for distribution grids with an isolated neutral point and $I_{>>}$-$t_{>>}$, $I_{>}$-$t_{>}$, I_e-t_e (earth fault protection) for distribution grids with a grounded neutral point.

In case of a double busbar system the coupling breaker E is protected according to the switch-onto-fault principle. This means that the protection relay is enabled for 3 – 5s directly after switching on the coupling breaker. After this time interval the protection relay is disabled.

Setting rules

In order to create a selective protective scheme the subsequent IOC protection relays have to be equipped with proper pickup values which are tuned to each other. The coordination starts with the last relay in a distribution feeder. In the case of the distribution grid of figure 1 the relay farthest away from the substation is D. The fault clearing time of this relay position is the lowest and is set to 0.3 s. This setting holds for $I_{>>}$, $I_{>}$ and I_e. The fault clearing time of the subsequent upstream relays (C and B) is graded with 0.3s which results for relay C in a fault clearing time of 0.6s and for relay B in 0.9s.

AUTOMATED ANALYSIS OF PROTECTIVE SYSTEMS

Due to the large number of networks that had to be analysed in a relatively short time, Stedin decided to focus on an automated analysis to perform a quick scan on all protection settings. All networks already were modelled in detail for asset management and network analysis purposes. Also circuit breakers, including their protection devices, and fuses were modelled. A new dedicated analysis function has been developed to perform the quick scan on the protection systems.

For all expected short-circuit situations, the quick scan function analyses all protection, circuit breaker and fuse actions, both in the situations that all circuit breakers operate normally and in the situations that one circuit breaker or protection device malfunctions (i.e. fails to operate). In either situation the network should be protected according to the protection philosophy. This means that all short-circuits should be switched off as quickly as possible and in such a way that the amount of customers that are not served is as small of possible.

Calculation options

The quick scan automatically simulates short-circuits on all nodes and in all cable connections. There are no overhead line connections in the Stedin MV network. For all cables a number (from 0 to 9) of equidistant fault locations will be evaluated. Another option is whether to simulate short-circuits physically close to the connected nodes or not. All types of short-circuits can be analysed: phase-ground, phase-phase-ground, phase-phase and three phases. The resistance on the fault location is 0 Ohm or a user specified value. Also protection device malfunction is an option.

Simulation

All short-circuit calculations will be based on the active network model, initiated from the load flow situation. Short-circuits and switching actions will be applied sequentially. For each step during the switching sequence, all network currents and voltages are calculated.
For each short-circuit scenario, the quick scan determines which protection devices will pick-up and it determines their delays before a trip signal will be produced. At the

delay time plus switching time, the corresponding circuit breaker will be opened (or the fuse will melt). In the new situation it will be established whether the short-circuit has been cleared or not. If not, for all other protection devices it will be established whether they stay in the pick-up state or that they fall. Again the tripping actions will be determined and circuit breakers will open until the short-circuit has been cleared. If a circuit breaker or its protection device fails to operate, the back-up protection/breaker will operate according to the settings.
In each simulation the complete sequence from short-circuit to the stationary end situation, when no circuit breaker or fuse operates, will be evaluated. For each simulation is recorded:

- Protections that switch off and their operating time.
- Thermal load of branches (I^2t).
- Currents in the stationary situation.

Results and problem report

The quick scan produces an overview of short-circuit situations that result in one or more of the next possible problems:

- Short-circuit not switched off
- Margin too small
- Not selective
- Thermal overload

The situation that a short-circuit is not switched off may have several causes. For instance, the measured current can be too small for the protection to trip. Also, in the case that the primary protection that fails to operate, the short-circuit current could be too small for the back-up protection to cause a trip signal.
In the case that a protection trips correctly, but that the short-circuit current is only up to 20% larger than the set value, this will result in a problem report, mentioning that the margin is too small.
Each short-circuit should be isolated in such a way that the number of customers not served is as small as possible. The software analyses whether the operating circuit breakers act selectively.
For all branches the thermal load is calculated during the complete short-circuit sequence. If (for at least one case) the I^2t energy is too high, a problem report will be generated. Also, if at the end of the sequence the stationary current is higher than the rated current, a problem will be reported.

In this way, the analyst receives a comprehensive report, specifying the number of more or less severe problems. By changing the calculation options, the analyst can see whether the problems are caused by a common cause, e.g. no protection against phase-ground faults or no correct back-up.

Example

A sample distribution network of 97 nodes and 111 cable connections has been scanned. The options were:

- Two phase and three phase faults
- One fault in each cable
- Fault impedance: 0 Ohm
- One protection/CB/fuse will malfunction

Since the network is not grounded, no phase to ground faults are evaluated. The result is graphically presented in the next figure. All nodes and branches, at which a fault does not result in any problem in the network, are coloured black. All nodes and branches, at which a fault results in at least one problem in the network, are coloured orange.

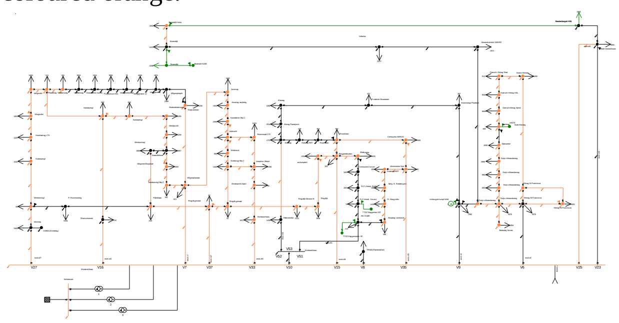

Figure 2: *Sample distribution network after analysis*

In this network, a short-circuit at 56 nodes and in 69 cables will result in a thermal overload when one protection malfunctions. A second calculation without the option to simulate one protection/CB malfunction, shows that there will be no problems reported. With this information, the analyst may conclude to check the back-up function in the network, both in the network model and in the real system.

RESULTS

All medium voltage grids are evaluated via the automated analysis procedure as described in the previous section. This has resulted into two sets of grids, one with protection problems and one without. Roughly, 80% of the evaluated MV-grids exhibit one or more of the discussed protection problems. To solve these protection problems, each grid has to be studied separately in detail resulting in an improved protection coordination and reduction of fault clearing time. Moreover, in case the current protection relays cannot accommodate the new proposed settings, replacement of these relays is also proposed. In this section common protection problems found in during the evaluation are discussed.

Fault detection problems

The majority of the protection problems found during the evaluation can be related to coordination problems and fault detection problems. An example of a fault detection problem is the detection of single phase-to-ground faults with an ordinary overcurrent protection relay. Shown in figure 3 is an example of these type of relays. In the past, from a cost saving perspective, a single protection device has been installed to detect both phase faults and single phase-to-ground faults. The structural analysis of the MV-grids has shown that this approach can lead to single phase-to-ground faults which are not always detected properly. In this case the analysis function has reported that the short circuit is not switched off or the margin of the detection fault current is too small. In practice this protection problem has led to a fire in two secondary substations in the last couple of years.

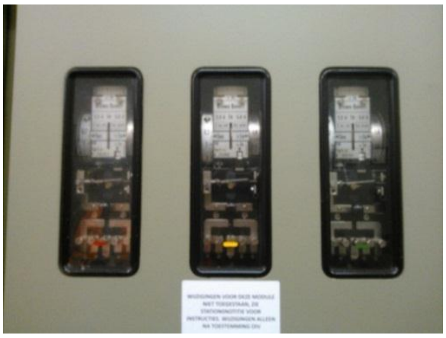

Figure 3: *Example of electromechanical relays without earth fault detection*

This type of problem is solved by replacing the installed protection relays with relays which have a separate phase fault and earth fault element. Application of these types of relays improve the sensitivity of single phase-to-ground detection without affecting the detection of phase faults.

Coordination problems

A coordination problem which is commonly found during the evaluation is discussed using the network shown in figure 4.

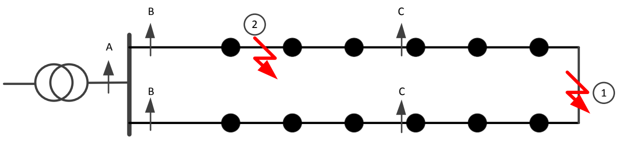

Figure 4: *Typical MV-feeder operated as a closed loop ring structure*

Figure 4 depicts an MV-feeder which is operated as a closed ring. The vertical arrows indicate the location of a circuit breaker including protection device. The coordination of the protection devices are given in table 1.

Table 1: *Coordination of protection devices A, B and C*

Protection device	Time setting [s]
A	1.5
B	0.9
C	0.6

In figure 4 two fault locations are indicated. For fault location 1 the protection devices C detect the fault and the fault is cleared in 0.,6s. The analysis tool indicates that faults in this part of the feeder are properly detected and cleared. For fault location 2 the performance of the protection scheme differs. Without studying the fault current behaviour in detail, one should expect that protection device C is opening the loop before protection device B clears the fault permanently. This is true for most fault locations between protection devices B and C. however, for some fault locations the switching order is different. For faults close to the substation, protection device B will sense a large fault current, while the contribution via the MV-feeder is modest and will not exceed the pickup level of protection device C. Hence, first protection device B will clear the fault in 0.9s and after opening the circuit breaker the fault current will exceed the pickup level of protection device C which will clear the fault in 0.6s. This mechanism is discussed in more detail in [1]. Due to this sequential fault clearing the total fault clearing time is 1.5s. This is also the fault clearing time of protection device A which acts as a backup protection. As a result protection device A will switch off the complete substation. In practice this has occurred several times. This issue is solved by increasing the fault clearing time of protection device A by 0.3s. An additional solution is to modify the operation of these types of MV-feeder from closed loop to radial has been made and applied where possible. The transition from closed loop to radial also solves the possible unselective fault clearing, caused by the fact that the settings of the protection devices C are equal to each other.

CONCLUSIONS

In this paper a project is discussed in which all transmission and distribution grids in the Stedin service area were be checked on a proper protective system. due to the fact that 170 distribution grids have to be checked, the analysis of the networks has been automated. After analysis, the majority of the reported problems appeared to be fault detection problems and coordination problems. These problems are solved by modifying the relay settings according to the standardized setting rules, exchange of protection devices and, incidentally, changing the protection concept. As a result the protection devices are better coordinated and fault detection is better guaranteed.

Along with the technical issues, the project resulted in some organizational issues as well. Optimizing the protection settings is the first step but managing the protection settings including firmware and all related parameters is an important next step. These issues are also addressed in the Stedin organization.

REFERENCES

[1] E. Parabirsing, 2011, 'Analysis of protection malfunctioning in meshed distribution grids', *proc. Of CIRED 2011*